→ TECHNOLOGIES FOR EUROPEAN LAUNCHERS

European Space Agency

An ESA Communications Production

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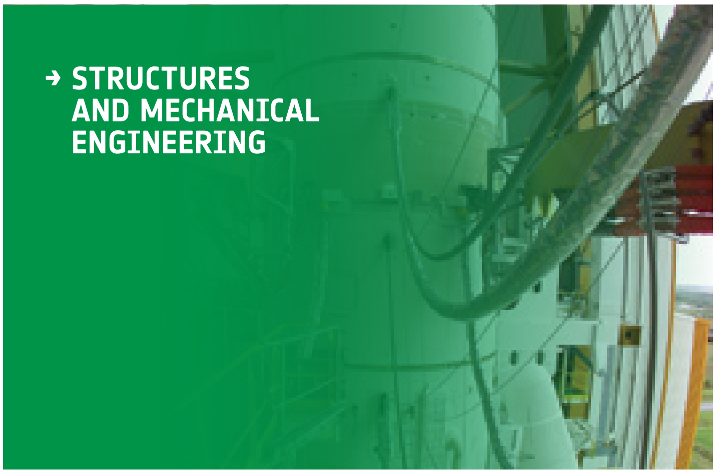


Introduction

Technologies for European launchers and new market requirements

For decades, the development of new launch systems has focused on increasing lift capability and reliability. Programmes conducted on behalf of ESA have supported industry in acquiring and mastering the basic and advanced technologies required to develop, manufacture and operate the most successful launch vehicles of their times.

Although Ariane has been setting the standard for the launch industry worldwide for more than 25 years, new challenges will have to be met in the coming years to ensure the viability of Europe's autonomous access to space and to keep the competitiveness of the European space transportation industry, whose skills are recognised at international level and have already led to major export contracts with vehicle prime contractors in the US and Japan.

Future European launch systems will not only have to deliver the right masses to the right orbits, but they will also have to be able to do it for any mass and any orbit, even if it requires complex manoeuvres. They will have to comply with new space regulations, in particular regarding debris mitigation through the deorbiting of upper stages. Most of all, they will have to provide reliable, flexible and timely launch services at a fraction of today's cost.

In order to prepare to face these challenges, ESA has started a series of new programmes in space transportation:

- Adapted Ariane 5 ME (Midlife Evolution) aims at improving the capacity of the Ariane 5 launcher to increase its payload capacity and enable it to perform complex deployment manoeuvres to a range of orbits where the current version cannot deliver payloads in an efficient way.

- Ariane 6 aims to become Europe's workhorse for institutional missions together with Vega in the next decade. Ariane 6 is building on 10 years of activities carried out under the Future Launchers Preparatory Programme (FLPP). It aims at continuing to guarantee access to space for Europe, improving the competitiveness of the launch systems without the need for Member State accompaniment funding for launcher exploitation. It will benefit from synergies with common elements developed through the ongoing activities of Adapted Ariane 5 ME, in particular for the upper stage, and through Vega evolution.

- Vega is ESA's new vehicle for lightweight missions. It addresses the lower segment of the launch market while demonstrating new technologies in materials, structural and mechanical components, as well as advanced avionics, under flight conditions.

- The Intermediate Experimental Vehicle (IXV) is a testbed for technologies required for atmospheric reentry and recovery. These include highly autonomous and modular subsystems that will help to expand the flight envelope able to be accessed in the future.

- As the ESA launcher technology programme, FLPP is maturing technologies to enable and sustain the development and evolution of current and future launchers. It is also investigating advanced launch vehicle concepts and technologies in the longer term. Special attention is being paid to preserving the expertise and evolution of the industrial setup in the launcher sector, as well as minimising the environmental impact of launch vehicles through technology matured in line with ESA's Clean Space Initiative.

This brochure highlights 44 examples of new advanced technologies developed or being developed by ESA's industry partners for these five programmes for future launch vehicles: propulsion (liquid, solid and hybrid), mechanical and structural components, and avionics.

These are 44 ways of demonstrating the knowhow of European industry and its efforts to innovate to ensure the long-term viability of Europe's access to space. For each one, ESA and its partners have identified the needs, confronted the technology challenges and made the best of existing experience in order to define, develop and qualify competitive solutions that will be applicable to future European launchers. They could even, sometimes, be exported to support our international partners' own efforts. This would be win–win cooperation, with European systems benefitting from the scale effects to reduce their own production costs.

These efforts illustrate the importance of the strategic asset represented by European savoir-faire in multiple fields, including thermo-structural materials, electric valves, advanced propulsion subsystems and smart avionics, born from years of research and development efforts, fostered by continuous support from ESA and national agencies. This unique expertise is key to Europe maintaining its leading position in autonomous access to space, a prerequisite for the success of all other European space ventures.

Background image: ESA–S. Corvaja

→ AVIONICS

ESA–S. Corvaja

→ INTELLIGENCE INSIDE

Future space vehicles will have to be able to complete less generic and more complex missions with many new requirements. To perform these at a competitive cost, they will need new flexible, adaptable and robust avionics, easier and safer to operate in order to streamline mission management and reduce human intervention. Modular designs will be key to achieving this capability, taking benefit from the rapid rise in computing power made by new-generation processors and the impressive advances made in new sensor technologies. The alliance of the two will help a vehicle to monitor the status and health of its own subsystems in real time and in flight, and to adapt its performance accordingly. Moreover, the use of smarter, lighter, smaller and less power-consuming avionics will reduce the mass of equipment bays and thus increase payload capacity.

→ VEGA ONBOARD COMPUTER

RUAG Space

Programme

vega

Other applications

ariane 5

ariane 6

What is it for?
The onboard computer is the launcher's 'brain'. It integrates the mission's flight software and processes the data from the vehicle's sensors, including inertial navigation, and delivers commands to the stages and subsystems to achieve the required orbital injection parameters.

What is the technology challenge?
Compared with the computer used in Ariane 5 before 2012, the Vega computer offers far more processing power, yet is significantly smaller and lighter.

What is European industry's expertise?
RUAG Space (formerly SAAB Space) has developed all of the computers flown on the various versions of the Ariane launchers for more than three decades. They all feature a robust and fault-tolerant design, high error detection coverage and components immune to radiation events.

What will be the resulting competitive edge?
A powerful onboard computer can run more sophisticated software that will improve flight control robustness and enable complex missions with multiple payloads to be injected into different orbits.

ADVANCED AVIONICS

Airbus Defence & Space

Programme

flpp

Other applications

vega pride ariane 6

What is it for?
The search for cost efficiency in the design of a new generation of launchers includes the evaluation of innovative avionics concepts based on new technologies in aerospace electronics and other time-critical systems, which are evolving at a very fast pace. Preparatory activities will focus on space application requirements and architectures but not on pre-development of actual systems that would likely be obsolete before their first flight.

What is the technology challenge?
The applicability of emerging protocol standards for launch systems such as Time Triggered Ethernet, new redundancy features targeting simplification of software applications, and optical fibres for reducing the harness mass will be assessed through breadboard testing.

What is European industry's expertise?
Airbus is leading the preparatory activities, building on its experience acquired in the development of numerous avionics systems, such as Ariane 5, the Automated Transfer Vehicle and an onboard data management system for the International Space Station. Its consortium includes competences from ACRA Control (Ireland), In Tune (Ireland), CRISA (Spain), Fiber Sensing (Portugal), RUAG Space (Austria, Switzerland, Sweden) and TTTech (Austria).

What will be the resulting competitive edge?
This assessment will be key to making sound decisions on the avionics architecture when designing the Next-Generation Launcher (NGL). Robust and reliable state-of-the-art avionics will improve the capacity, flexibility and robustness of the NGL, and prevent early obsolescence that would require costly requalification processes during its operational life.

MULTI-FUNCTIONAL UNIT

CRISA

Programme

vega

Other applications

ariane 6 pride

What is it for?
The Multi-Functional Unit (MFU) provides control, monitoring and power distribution to the different subsystems. In particular, on Vega it controls a total of 28 pyrotechnic functions with their redundancies and powers 10 electrovalves.

What is the technology challenge?
The MFU has to ensure efficient and redundant delivery of commands and power, with redundancy, while controlling its own logic by reporting all telemetry and commands it issues and receives to the communication system and report to the ground.

What is European industry's expertise?
CRISA has been providing sequential electronics for Ariane 5. These actuator control and supervision units drive most of the actuators within the launcher, like electrovalves, pyrotechnic devices and payload loops. More than 200 such units have flown.

What will be the resulting competitive edge?
The MFU is a critical element of the launcher's avionics. Its performances are critical for the vehicle's robustness and reliability.

→ FIBRE BRAGG GRATING SENSOR SYSTEMS

Fiber Sensing

Programme

flpp

Other applications

pride

ariane 6

What is it for?
To achieve a high success rate, a launch system has to be both reliable and robust. This means that numerous parameters have to be monitored and transmitted to the ground for precise monitoring of the launch behaviour. The network of sensors is traditionally connected to the equipment bay through a heavy harness of copper cables.

What is the technology challenge?
The replacement of copper harnesses by optical fibres would yield several major improvements: high data rates, immunity to the electromagnetic environment and reduced mass and cost, especially for assembly, integration and testing (AIT). In addition, it could allow the introduction of fibre Bragg grating sensor technology, with the inherent advantage of high multiplexing capability.

What is European industry's expertise?
Fiber Sensing is a leading company in the development and production of advanced monitoring systems based on fibre Bragg grating technology for the energy, oil, rail and aerospace industries. It has been studying this technology under the FLPP programme, emphasising harness optimisation and data acquisition and system analysis, in particular for AIT. A breadboard harness will be tested in the laboratory environment to assess the advantages and risks for the design of future launcher avionics.

What will be the resulting competitive edge?
Fibre Bragg grating sensor technology is considered to be the most suitable and reliable technology for long-term sensing and structural health monitoring, having become the natural substitute for all conventional technologies available.

→ SAFEGUARD MASTER AND REMOTE UNIT

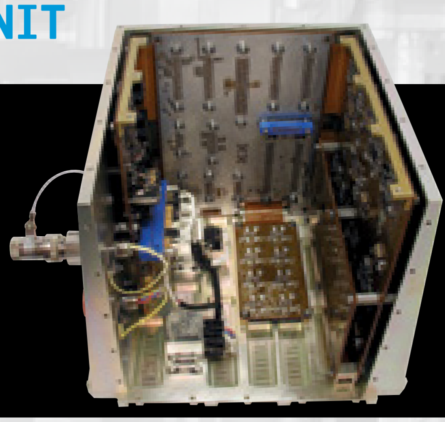
Selex Galileo

Programme

vega

Other applications

ariane 6



What is it for?
The safeguard system enables flight termination both autonomously in case of untimely stage separations or under command from the ground if the launcher veers off course and could become a threat to people or to the environment.

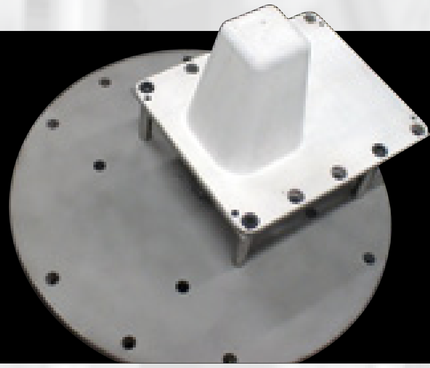
What is the technology challenge?
This critical system is completely segregated from the functional chain and has to remain operational even in the event of a major system failure on board the vehicle. For maximum reliability, it has two independent chains, each consisting of one Safeguard Master Unit and two Safeguard Remote Units.

What is European industry's expertise?
Involved in space activities since the 1960s, Selex Galileo is an experienced provider of power distribution and pyrotechnic control systems for space applications, both on satellites and launchers.

What will be the resulting competitive edge?
New regulations on launcher safety have been introduced in French Guiana and are likely to become an international standard. Safeguard systems, designed for worst-case scenarios, will be required for all new generations of launch systems.

→ TELEMETRY ANTENNA

Rymsa



■ Programme

vega ixv

■ Other applications

ariane 6 pride

■ **What is it for?**

The need to relay information from the launch vehicle's system and sensors requires a set of antennas for reliable transmissions to the ground in various flight configurations. On Vega, these are classic conical S-band transmission antennas. IXV relies on aperture-coupled microstrip patches with a multilayer structure.

■ **What is the technology challenge?**

Vega's antennas have their own thermal protection to combat the thermal fluxes during the ascent phase of the flight. IXV will have to withstand much higher aerothermal conditions so the antenna is designed to operate under a fibreglass dome covered with thermal insulation. The antenna's design is optimised to cope with the signal degradation caused by this protection and to ensure that the resulting radiation pattern complies with the stringent conditions imposed by the limited visibility windows and the presence of the thermal protection layer.

■ **What is European industry's expertise?**

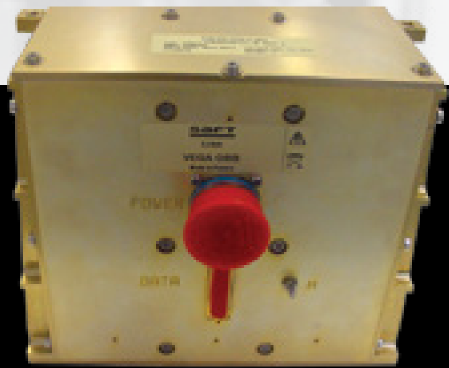
Rymsa has more than 30 years of experience in the design, manufacture and supply of onboard antennas and passive microwave equipment for satellites.

■ **What will be the resulting competitive edge?**

The proposed patch technology for the IXV antenna design is highly efficient and effective because it is simple and easy to mount, while offering a high bandwidth.

→ ONBOARD BATTERIES

Saft



■ Programme

vega

■ Other applications

ariane 5 ariane 6 ixv pride

■ **What is it for?**

During flight, all the electrical power to feed a launcher's subsystems is provided by batteries, which have to deliver continuous and stable performance in all kinds of dynamic and thermal conditions. These batteries support vital launch vehicle systems, including safeguard and pyrotechnic subsystems, thrust vector control, pump activation, avionics and telemetry.

■ **What is the technology challenge?**

On Vega, the batteries play a key role by powering the electromechanical actuators for the thrust vector control system on each stage, and in particular on the P80, the largest solid stage ever to use such actuation. Saft has developed innovative Li-ion battery systems for this purpose. One type of cells has been selected for the first three stages, which require high current delivery. Another type is used in the two sets of batteries on the upper stage, one for thrust vector control and the other for the vehicle's guidance, navigation and control systems. They supply power at a lower rate but for a much longer time.

■ **What is European industry's expertise?**

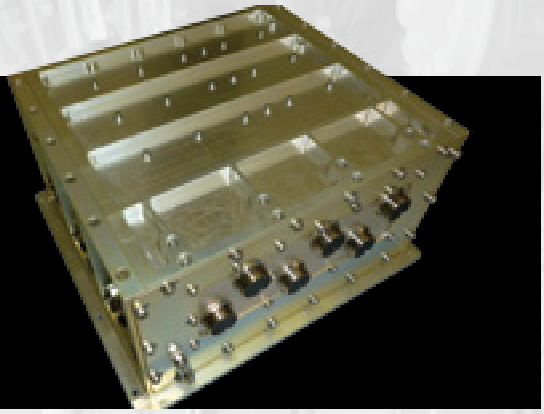
Saft has over 40 years of experience in the design, development, manufacture and supply of onboard battery systems for satellites, launchers and other space vehicles. On Ariane, Saft batteries are found in the solid-propellant boosters, the cryogenic core stage, the cryogenic upper stage and the vehicle equipment bay.

■ **What will be the resulting competitive edge?**

The high performance and reliability of European space-qualified batteries have already guaranteed their export to international prime contractors, telecom operators and space agencies. Their continuous improvement will increase their market share.

→ IXV ONBOARD COMPUTER

QinetiQ



■ Programme

ixv

■ Other applications

pride

■ **What is it for?**
On a mission as complex as IXV's, the onboard computer (OBC) will be in command of all of the vehicle's functions and data-handling tasks from its release by the launcher to its recovery at sea. To comply with the stringent mass and thermal constraints inherent to reentry missions, it was designed in a single-chain configuration.

■ **What is the technology challenge?**
The highly modular scheme, adapted from the Advanced Data & Power Management System flown on Proba-2, imposes challenging constraints on the development of the new interface capabilities with the IXV vital functions, sensors and telemetry links.

■ **What is European industry's expertise?**
QinetiQ Belgium (formerly Verhaert) benefits from more than 40 years of experience as a space system integrator, with more than 100 systems delivered for manned space stations, satellites and interplanetary missions, including the highly autonomous Proba-1 and -2 satellites.

■ **What will be the resulting competitive edge?**
The new interface capability, based on a 1553 bus, will ensure the compatibility of QinetiQ modular OBCs with a much wider range of satellites and applications.

→ ONBOARD SOFTWARE TECHNOLOGY

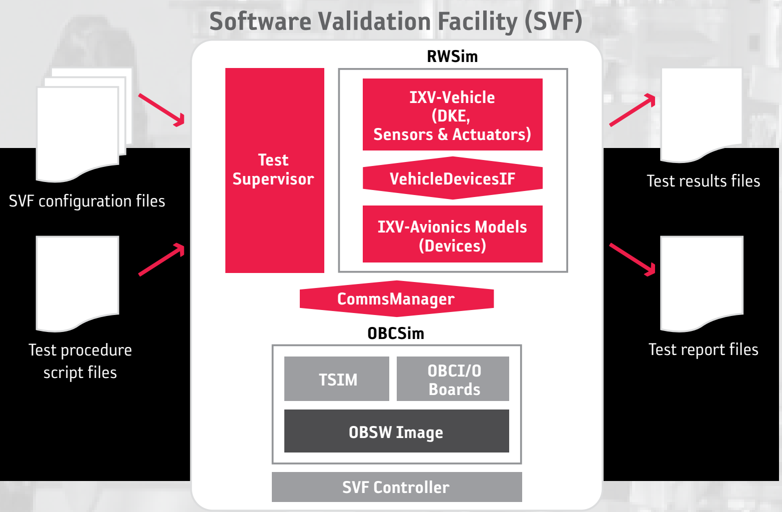
GMV, GTD Sistemas de Información

■ Programme

ixv

■ Other applications

pride



■ **What is it for?**
The IXV onboard software (OBSW) is under development by GMV and incorporates the algorithms for the mission and vehicle management (MVM) as well as guidance, navigation and control (GNC). It consists of two layers: the basic layer provides the operating system, a board support package and device drivers, while the service layer supports the application software for MVM and GNC tasks as well as error handling.

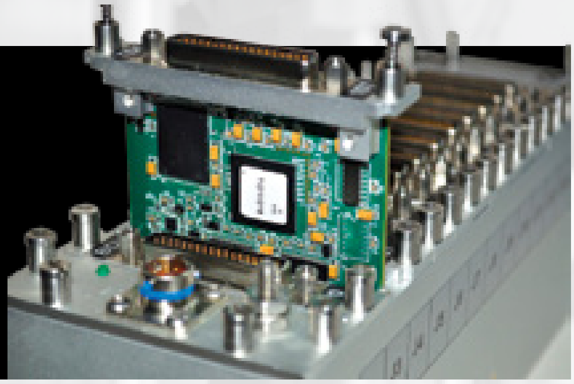
■ **What is the technology challenge?**
Unlike other spacecraft, IXV will fly a short mission with highly dynamic, evolving flight conditions, especially during the reentry phase. This means that its OBSW will not be able to be maintained and upgraded in flight. It will have to be highly autonomous and perform perfectly for all of the mission duration.

■ **What is European industry's expertise?**
The OBSW will be first validated on a Software Validation Facility developed by GMV and then qualified on the IXV project's Avionics Test Bench. In parallel, GTD will conduct an independent software verification and validation. Since its creation in 1984, GMV has been involved in the design, development, validation and verification of onboard software and their maintenance systems, for all kinds of projects, missions and platforms. In the last decade, GTD Sistemas de Información has become a leading company in software development for space applications, especially in monitoring and control systems and ground segments.

■ **What will be the resulting competitive edge?**
The IXV OBSW is a new step in flight software development in Europe in terms of complexity, reliability, autonomy and robustness. European industry's capacity to develop such systems will pave the way for more demanding missions, in particular in human spaceflight, where a high level of reliability and robustness is required, and for highly autonomous interplanetary exploration probes.

→ SMART AND MODULAR ETHERNET-BASED DATA-HANDLING SYSTEM

ACRA Control



■ Programme

ixv

■ Other applications

ariane 6

pride

■ What is it for?
During its mission, IXV will collect very large amounts of heterogeneous data, from multiple sensors and subsystems. It will thus require an efficient data-handling system to acquire, store, encode and process these data to the transmitter back to the ground. ACRA Control is developing an innovative and modular system based on the Ethernet protocol and a tuneable core algorithm, able to store data when the spacecraft flies into no-visibility zones and play them back at accelerated speed when a ground station is visible.

■ What is the technology challenge?
Although the Ethernet protocol is universal on the ground, it is still a highly innovative approach in space applications and its compliance with space constraints has to be tested and qualified, as well as its compatibility with the assembly, integration and testing processes and tools used in the space industry.

■ What is European industry's expertise?
ACRA Control has accumulated 20 years of experience in supplying airborne data acquisition networks and recording systems as well as realtime data processing ground stations to the aerospace industry.

■ What will be the resulting competitive edge?
The Ethernet protocol facilitates the design, integration and testing of complex integrated systems. It limits the amount of serial cable bundles, thus reducing the risk of human error, and can support very high-bandwidth requirements (up to several Gbit/s) without imposing strict timing or transmission order. This modular 'plug-and-play' concept for data handling will apply to a wide range of missions with limited access to ground stations, from low-Earth orbit spacecraft to deep-space probes.

→ DESCENT AND LANDING SYSTEM SYNTHESIS TEST TECHNOLOGY

CIRA

■ Programme

ixv

■ Other applications

pride

■ What is it for?
At the end of its descent following atmospheric reentry, IXV will deploy a main parachute and immediately after splashdown it will inflate flotation balloons and activate beacons. To ensure the success of the mission, the performance of the flight software designed to trigger these events, as well as the recovery procedures for the vehicle, have been assessed in conditions as close as possible to the real flight. A full-scale prototype was dropped by a helicopter from an altitude of 3000 m in June 2013 and safely splashed down.

■ What is the technology challenge?
The IXV prototype incorporated flight models of the main parachute assembly, the parachute and flotation panels, the flotation balloons, the beacons and the ablative thermal protection system, which had to be integrated and tested. The prototype was extensively instrumented in order to monitor the descent parameters and record the loads at splashdown. The drop test also required complex coordinated operations between a military helicopter, the mission control centre and a recovery team.

■ What is European industry's expertise?
CIRA, the Italian aerospace research centre, has already conducted drop test campaigns in 2007 and 2010 under the Unmanned Space Vehicle programme. These drop tests were conducted under a similar operational and recovery scenario within the same test range.

■ What will be the resulting competitive edge?
With this testing technology, it is possible to reproduce with high fidelity the conditions of the final part of the IXV mission, which is highly critical, as demonstrated by the failure of some similar projects by other national and international space agencies during the descent and landing phase. Mastering this technology will reinforce European industry's attractiveness as a valuable partner on future projects involving unmanned reentry vehicles.

→ PROPULSION

ESA/CNES/Arianespace/Service Optique CSG

➜ THE THRUST YOU NEED AT THE BEST COST

Propulsion is one of the primary cost drivers in any launch vehicle design. So, the quest for higher competitiveness has to pass through the search for the highest efficiency levels in liquid and solid propulsion systems. The goal is not necessarily to get the highest thrust at the least cost, but to deliver increased performance in terms of reliability, availability, throttle and restart capacity as well as specific impulse (efficiency in propellant consumption), while reducing recurrent manufacturing costs. This can be achieved through the introduction of new propulsion cycles (expander or staged-combustion), optimised designs for subsystems, new materials and the best use of decades of industrial investment in technological knowhow, in order to develop not the most powerful liquid engines and solid motors but those that best fit the needs.

➜ THRUST CHAMBER TESTING AT SIMULATED ALTITUDE

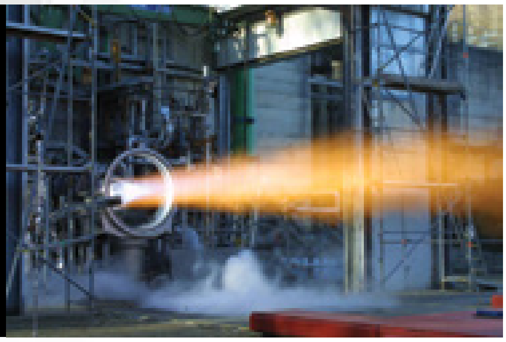
Airbus Defence & Space

Programme

ariane 5

Other applications

ariane 6



What is it for?
Since it is based on an expander cycle, which uses its cryogenic propellant to cool its thrust chamber and then the resulting gaseous propellant to drive its turbopumps, the Vinci engine's performance requires a perfect knowledge of its thrust chamber behaviour under flight conditions.

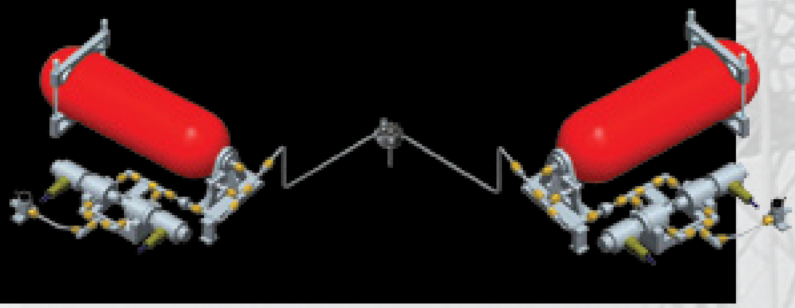
What is the technology challenge?
To conduct such characterisation tests on the ground, the P3.2 high-pressure cryogenic test facility in Lampoldshausen, Germany had to undergo major modifications from 2009 to mid-2011 with a complex arrangement of feed lines and control valves to adapt to the 380 bar of the liquid hydrogen inlet. As for the development of the HM-7 engine in the 1970s, it also required the installation of a vacuum chamber to simulate high-altitude operations and a supersonic diffuser to maintain a low-pressure environment while the thrust chamber was performing. However, due to the new cycle, which allows improved performance and higher engine reliability, operations of the thrust chamber required five control loops operating in parallel, which had never been done by Airbus before.

What is European industry's expertise?
Airbus and DLR have four decades of experience in conducting thorough firing test campaigns in Lampoldshausen. For this campaign, following four acceptance hot firing tests, 28 development firing tests through November 2011 logged 2605 seconds of cumulated thrust chamber firing time monitored by over 240 sensors and completed the validation of the Vinci thrust chamber design.

What will be the resulting competitive edge?
This campaign also demonstrated the possibility of adapting the existing testing facilities for highly complex test campaigns for future programmes.

→ RESTARTABLE CRYOGENIC ENGINE IGNITION SYSTEM

Aerospace Propulsion Products BV



- **Programme**: ariane 5
- **Other applications**: ariane 6

What is it for?
Unlike its predecessor HM7, the cryogenic Vinci engine will have the capability to perform up to five burns and thus to conduct complex manoeuvres that cannot currently be performed by Ariane 5 ECA, from the deployment of satellite constellations to the delivery of payloads into high-perigee transfer orbits or escape trajectories. One of the features that will give the Vinci engine its restart capability is a new ignition system developed by APP.

What is the technology challenge?
The Vinci Ignition System (VIS) uses gaseous oxygen and hydrogen from a blowdown system and two redundant spark plugs (supported by redundant electronic systems) to generate a hot plume to ignite the engine. The spark plug system is fed by two low-voltage lines, and the high voltage required to produce the electric arc is generated by two ignition coils – one per plug – much like in traditional internal combustion engines.

What is European industry's expertise?
APP (formerly Stork) has already produced hundreds of igniters for cryogenic and solid-propellant propulsion systems flown on Ariane and Vega vehicles. This new highly robust design, able to conduct up to five ignition sequences, incorporates all the knowhow developed by APP on redundant ignition systems since 1998, and in particular work conducted on spark plugs since 2008.

What will be the resulting competitive edge?
This design is now available to replace the non-redundant ignition system that has been used for all of the Vinci engine testing to date.

→ LOW-TEMPERATURE BALL-BEARING JOINT TEST RIG

Ruag

- **Programme**: ariane 5
- **Other applications**: ariane 6

What is it for?
The ball-bearing joint – or Cardan – is the articulation that allows steering of the Vinci engine in order to orientate its thrust and guide the stage. It has to operate under very low temperature (120K) and high-stress conditions.

What is the technology challenge?
To demonstrate the joint's performance, a special test rig had to be developed that would simulate the harsh conditions it will have to endure during flight and enable accurate measurement of friction torque loads, deformation and clearance of the Cardan as well as strain of its structure, angles and cycles, forces and torque loads and temperature of interface plates.

What is European industry's expertise?
Ruag Space Austria took benefit of three decades of expertise in complex space mechanisms for satellites, launchers and ground support equipment to design an advanced test bench that uses computer-controlled hydraulic actuators to apply all required 3-axis load combinations on the ball-bearing joint while the interface plates temperatures are precisely adjusted with liquid nitrogen flowing through embedded pipes and thermal insulation from the rig's structure. Friction moment is measured with a quartz platform, which is maintained at ambient temperature to ensure the highest accuracy in the data.

What will be the resulting competitive edge?
This combination of highly demanding mechanisms, thermal control and measurement systems is key to the qualification of this critical system, required to integrate the Vinci engine into a high-performance propulsion system.

→ COMPOSITE DEPLOYABLE NOZZLE

Herakles

Programme ariane 5

Other applications ariane 6

What is it for?
A significant improvement in engine performance at high altitude can be obtained by increasing the length and section of its exhaust nozzle to channel the gas flow. Such an extension translates into a better specific impulse – higher thrust per unit mass of propellant. However, it should not translate into a tremendous increase in mass and interstage length at launch.

What is the technology challenge?
The 2.85 m-long nozzle extension developed by Herakles for Vinci increases the nozzle's exhaust diameter from 700 mm to 2180 mm. It consists of three carbon–carbon/silicon carbide conical rings coated with thermostructural carbon–carbon radiative oxidation protection and two carbon–carbon cone-to-cone latching systems. The use of composite materials instead of metal yields large mass savings.

What is European industry's expertise?
A leader in thermostructural composite materials and in the development of nozzles, in particular for Ariane 5 booster stages, Herakles has already developed deployable composite nozzle extension systems and flown them on international launch vehicles. Since 2006, full-scale development models of Vinci nozzle extensions have been tested under simulated altitude conditions to up to seven life durations, reaching temperatures of over 1700K and sustaining transient loads at ignition and shutdown of the engine. More than 30 deployments were performed, including three in vacuum conditions.

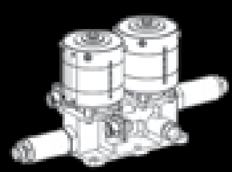
What will be the resulting competitive edge?
This robust and effective design, based on flight-proven technologies, will be key in achieving the targeted payload performance of Vinci-based upper stages.

→ HIGH-PRESSURE BISTABLE ELECTROVALVE

Techspace Aero

Programme ariane 5

Other applications ariane 6



What is it for?
To pressurise its propellant tanks, the new cryogenic upper stage of Adapted Ariane 5 ME has to carry a set of high-pressure helium tanks, filled on the pad. To support this system, Techspace Aero is developing a load plate design that incorporates two identical poppet electrovalves, one to ensure filling or emptying of the tanks on the ground, and the other to ensure helium distribution to the stage command system in flight.

What is the technology challenge?
In addition to 400 bar pressure levels and very low operating temperatures, technical requirements include limited mass and size together with low recurring costs.

What is European industry's expertise?
To achieve such constraints, the innovative design proposed by Techspace Aero, a long-time provider of valves for the space industry with more than 12 000 flights units flown with 100% operational reliability, will use the pressure of the helium flowing through the valve to assist the electrical actuator in opening or closing the valve. It includes an innovative bistable solenoid architecture to reduce the number of parts and thus the manufacturing cost, as well as a helium-assisted poppet to reduce the size and mass of the actuator. The concept also allows the integration of end stop sensors with limited impact on the overall mass.

What will be the resulting competitive edge?
With two similar electrovalves to perform the tasks, Techspace Aero will also benefit from economy of scale – all the more since this design will also be applicable to multiple other purposes, in the space industry as well as in ground-based gas management systems.

→ COMBUSTION TECHNOLOGY FOR EXPANDER AND STAGED COMBUSTION ENGINES

Airbus Defence & Space

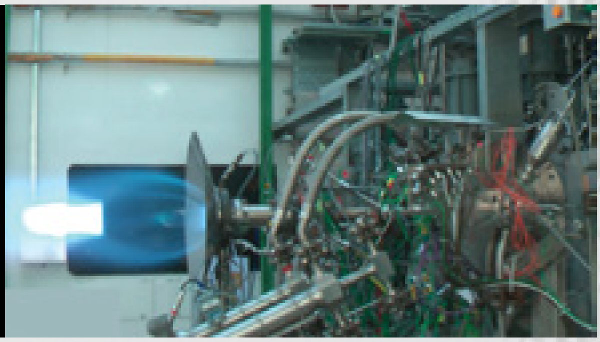
Programme

flpp

Other applications

ariane 6

future launchers



What is it for?

The mastering of new combustion cycles providing higher specific impulse than the gas-generator cycle used on current European cryogenic engines is an important element of the research and technology effort in space propulsion. The expander cycle, which is inherently reliable, has been introduced with the Vinci engine, while the staged combustion cycle is under evaluation through the SCORE-D (Staged Combustion Rocket Engine Demonstrator) project.

What is the technology challenge?

Airbus, which has been providing the combustion chambers of Ariane 5 Vulcain engines for two decades, is studying liquid–gas and liquid–liquid injector designs to maximise combustion efficiency and stability. It is also studying cooling channel layout and design and heat-resistant materials in conjunction with inner wall heat exchange adjustment to ensure life duration optimisation, fast thermal equilibrium and condensation avoidance. Subscale demonstrator combustion chambers are being designed and manufactured in order to test these technologies in real hot-firing conditions at low cost, to consolidate and improve the Vinci and SCORE-D designs.

What is European industry's expertise?

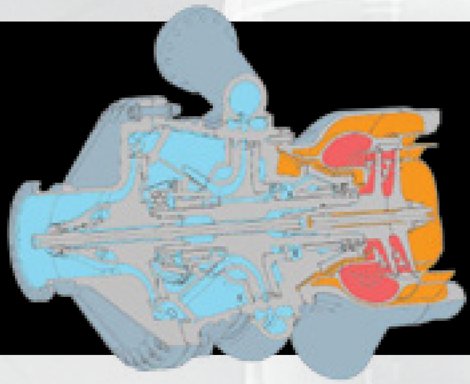
The consolidation of the physical models is essential to ensure the representativeness of subscale test conditions in support of subsequent full-scale testing of the combustion chamber and nozzle extension technologies. These tests will validate the design and characterise the operating domain before full engine testing.

What will be the resulting competitive edge?

An increase in the efficiency of propulsion systems would help to maintain and improve the competitiveness of Europe's space launcher industry.

> **Working on a new launcher, it's finding the new technologies of tomorrow and mastering the development and operations costs. For the teams, it is a wonderful adventure to live.**
>
> Alain Charmeau
> *CEO of Astrium Space Transportation*
>
> *Le Figaro*
> 7 July 2010

→ HYDROGEN TURBOPUMP FOR STAGED COMBUSTION ENGINE



Snecma

Programme

flpp

Other applications

future launchers

What is it for?
In a cryogenic engine, one of the most critical subsystems is the hydrogen turbopump, which has to deliver high power and high reliability within a limited volume and under extreme temperature (20K) and pressure (up to 380 bar) conditions, while operating with a compressible cryogenic fluid. Moreover, these challenges are met in a strongly cost-constrained approach.

What is the technology challenge?
Snecma, which designed and manufactures the hydrogen turbopumps for Ariane 5's Vulcain engines, is using innovative technologies matured in particular through FLPP to develop such a turbopump for the SCORE-D project.

What is European industry's expertise?
This advanced turbopump incorporates new approaches in terms of helium-free sealing in order to limit or suppress the need for helium gas venting before engine start. In the turbine's mechanical and aerodynamic design, new blade profiles are proposed for high mass flow in the subsonic environment as well as the use of materials resistant to hydrogen embrittlement. For rotor guidance, together with new clutchable axial bearings, hydrostatic bearings developed under the TPX programme are replacing traditional ball bearings to allow higher rotational speeds with good rotor dynamics. Finally, the new open impeller technology – also inherited from TPX– ensures the highest level of pressure rise per pump stage, thus meeting the engine's highly demanding overall pressure requirements with only a two-stage design, which translates into a reduced size and manufacturing cost.

What will be the resulting competitive edge?
Since propulsion accounts for a large part in the cost of a launch vehicle, an increase in efficiency while keeping the costs down would play a significant role in improving the competitiveness of future European launch systems.

→ SANDWICH TECHNOLOGY NOZZLE EXTENSION

GKN Aerospace, Force Institute

Programme

flpp

Other applications

ariane 5

ariane 6

future launchers

What is it for?
Regenerative cooling by the circulation of cold propellant inside the structure is a commonly used approach to ensure that engine nozzles withstand the high temperatures of the exhaust gases. However, it requires complex and costly manufacturing processes, with many hundreds of thin tubes manually welded together around a mandrel.

What is the technology challenge?
GKN Aerospace (formerly Volvo Aero) has been Europe's leader in cryogenic nozzles for three decades and it has developed a new process to manufacture them using a patented sandwich technology.

What is European industry's expertise?
The hundreds of tubes have been replaced by two sheet-metal cones. The inner cone features ducts machined by automated ultrasound-controlled milling to achieve a precision of some hundredths of a millimetre in sheet metal with a minimum thickness of 0.6 mm. The outer cone is welded onto the inner one by automated laser welding using realtime X-rays that detect the hidden weld joint. This innovative welding technique was developed by the Force Institute in Denmark, which also introduced new non-destructive testing processes. The result is a substantially stiffer and more robust sandwich nozzle.

What will be the resulting competitive edge?
This new technology has already been hot-fire tested on Ariane 5's Vulcain 2 engine and as part of the FLPP High-Thrust Engine project. It is also applicable to other engines developed in Europe or by international partners. To ensure readiness for future European programmes, upgraded sandwich nozzle extension manufacturing processes have been developed, especially to improve nozzle contouring, curved surface welding or ultrasonic control.

> **The fact that we have so many engineers, and all the more so many skilled engineers enables us to make the difference on the market. In an advanced technology venture, all the staff are pulled to the top, so it's a collective success. Suffering together to achieve your final goal is pleasant, and it makes you proud.**
>
> Yves Prete
> *CEO of Techspace Aero*
>
> *Périodique bimestriel de l'uWe*
> December 2011

→ STAGED-COMBUSTION ENGINE VALVES

Techspace Aero

Programme: flpp

Other applications: future launchers

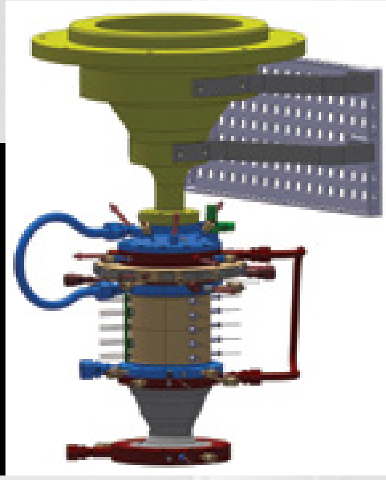
What is it for?
The staged-combustion cycle implies harsh performing conditions, with tubing and valves for both propellant at cryogenic temperatures and hot gases at very high temperatures.

What is the technology challenge?
To increase the performance of such valves as well as to reduce cost, Techspace Aero, Europe's long-time leader in regulation valves for space propulsion applications, has developed a set of valves for the FLPP SCORE-D project.

What is European industry's expertise?
These valves incorporate new technologies, such as a seal retraction system, to improve static and dynamic sealing in cryogenic environments, for both secured operations and reduced actuation requirements. Efforts have also been made on the generalisation of electric valves with position sensors and control systems technology, associated with engine health monitoring, and of propellant-aided valves, where part of the actuation is provided by the propellant pressure itself in order to minimise the need for external power supply. The use of rotating electric actuators to apply linear forces has been improved through transmission with optimised gear ratio in order to minimise the requested actuation torque – and thus the power consumption – while increasing the positioning accuracy. New electronic controls have been introduced to limit torque loads and attenuate shocks in order to optimise the valves' mechanical design. To validate and qualify these new designs, adapted cryogenic test benches were also developed. Similar efforts have been made with hot-gas valve technologies, especially for sealing and gear systems.

What will be the resulting competitive edge?
Engines based on the staged-combustion cycle are highly efficient and particularly suited to first stage or sustainer stage applications.

→ HIGH-PERFORMANCE STORABLE PROPULSION



Airbus Defence & Space

■ **Programme**

flpp

■ **Other applications**

vega

■ **What is it for?**
In the future, the development of new ‘smart’ upper stages or of some missions with enhanced orbital transfer capability will require the use of high-performance storable propulsion systems in a range of thrust that is currently not covered by European industry.

■ **What is the technology challenge?**
Such an engine would have to fit between the 500 N apogee thrusters for geostationary satellites and Ariane 5’s 29 kN Aestus engine, both developed by Airbus in Germany. Under the FLPP programme, Airbus is assessing new technologies to develop an advanced engine in the 3–8 kN range

■ **What is European industry’s expertise?**
Several technology challenges have to be met for an engine of that size. First, its combustion chamber is too small to be cooled by the sole MMH (monomethyl hydrazine) propellant flow. This has to be complemented by regenerative cooling using NTO (nitrogen tetroxide), which has a lower margin in temperature before boiling. After characterisation in the laboratory, an NTO-cooled combustion chamber has been designed and will be tested under hot-firing conditions. The size of the injectors is a challenge too in terms of manufacturing, inspection and cleanliness requirements. Several designs have been tested under hot-firing conditions, first as single elements, then as complete injector plates. Systems designed to prevent high frequencies have been introduced as a modular feature in the demonstration engine in order to test a large array of configurations and tunings. In addition, innovative processes are being matured to manufacture lightweight and lower-cost metallic nozzle skirts using radiative cooling.

■ **What will be the resulting competitive edge?**
This engine could be used to power future smart vehicles, from highly manoeuvrable upper stages to interplanetary probes or servicing spacecraft, developed in Europe or under international cooperation.

“

The fact that space technology has been a national priority in Norway for many years, with an active membership in the European Space Agency, is of utmost importance for the success of Norwegian space industry. Our contracts are important milestones in our continuous effort to satisfy demanding customers and demonstrate our capability to compete in the space market.

”

Morten Brandtzaeg
Executive Vice President, Nammo Missile Products Division

Nammo press release
2009

→ HYBRID AND MONOPROPELLANT ATTITUDE-CONTROL THRUSTERS

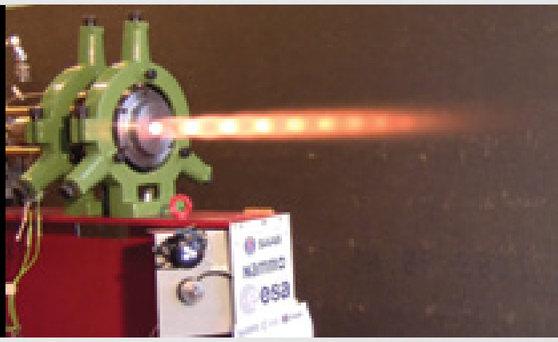
Nammo, SAAB-Dynamics

Programme

ariane 5

Other applications

ariane 6



What is it for?
To perform complex manoeuvres and accurate positioning for the release of its payloads, the Adapted Ariane 5 ME cryogenic upper stage will require a flexible and reliable attitude control system (SCATE), also to be used for propellant settling at the end of cruise phases prior to Vinci engine reignition.

What is the technology challenge?
For this purpose, Nammo, a pioneer in hybrid propulsion, has designed an ingenious integrated thruster concept, which combines green hybrid and monopropellant propulsion to achieve a wide range of modulated thrust levels, with high reliability at reduced cost. The proposed SCATE thruster will be fed with high-strength hydrogen peroxide, a powerful oxidiser, both non-polluting and storable. The hydrogen peroxide will be used as monopropellant by flowing through a catalyst unit that will decompose it into hot gas to deliver low, modulated or pulsed thrust for high-precision manoeuvring. Whenever a stronger boost is needed, the decomposed hydrogen peroxide will be fed into a hybrid propulsion chamber in order to burn a solid fuel and deliver a higher thrust.
Unlike solid propulsion systems, hybrid propulsion does not require a highly energetic solid propellant – thus reducing risks during handling – and it can be throttled, shut down and restarted at will.

What is European industry's expertise?
In 2010, on behalf of ESA's Hybrid propulsion Technology Readiness Programme, Nammo performed 49 firing tests of its thruster concept, 29 in hybrid mode and 20 in monopropellant mode.
In 2011, more than 40 additional tests were conducted to optimise the monopropellant mode for use on Ariane 5 ME.

What will be the resulting competitive edge?
In addition to a high-flexibility use on future upper stages, studies are under way on hybrid technology to scale the concept up for possible use on future sounding rockets and microsatellite launch vehicles.

→ HYBRID PROPULSION DEMONSTRATOR

Nammo

Programme

flpp

Other applications

Sounding rocket
Nanolauncher
Lander propulsion

What is it for?
Hybrid propulsion uses a solid fuel and a liquid oxidiser to deliver high thrust (like solid propulsion) but with a capacity to control throttle, shutdown and even restart (like liquid propulsion). Among its many advantages is the capacity to use non-explosive solid fuel and non-toxic storable oxidiser, both easier to transport and handle during processing than traditional solid and storable propellants.
In many ways, it combines the advantages of solid and liquid propulsion at a much lower manufacturing and operating cost.

What is the technology challenge?
Norway's Nammo, a solid-propulsion specialist, which has flown more than 1000 solid rocket motors for booster separation on Ariane 5, has been investigating modern hybrid propulsion since 2003 to characterise performance of various fuel/oxidiser combinations with different additives.

What is European industry's expertise?
Under ESA's FLPP a selection of the most promising propellant combinations has been made for testing at subscale level.
A configuration was then selected for the development of a hybrid engine demonstrator for full-scale 'battleship' ground testing.
With the development of dedicated analysis and design tools, this demonstrator will lead to the testing of a flightworthy version, which could later be introduced in future sounding rocket designs.

What will be the resulting competitive edge?
The objective is not only to increase European industry's knowhow in hybrid propulsion but also to demonstrate and quantify its advantages in terms of operational performance and procurement cost.

→ ADVANCED SOLID PROPULSION TEST BENCH

Avio

Programme

flpp

Other applications

ariane 5 vega ariane 6

What is it for?

Solid propulsion has long been identified as a cost-effective solution to deliver high thrust for core and booster stages, as demonstrated by the designs selected for Ariane 5 and Vega.

What is the technology challenge?

Despite a large amount of test and flight data, some of the physics of solid propulsion is not yet fully modelled. This prevents satisfactory evaluation of new designs through numerical simulations. Among the primary concerns are pressure oscillations, especially on segmented propellant loads, which can be highly critical in the upgrade of existing motors (P250 and MPS-2 for Ariane 5 upgrades or P120 for Vega upgrades). Since subscale testing is not fully representative owing to numerous physical constraints and full-scale firing tests are too expensive for flexible and comprehensive studies, the need for a flexible solid propulsion test bench to experiment with new booster configurations for pressure oscillations and innovative technologies (such as thermal protection, sensors or low-cost nozzles) was identified long ago.

What is European industry's expertise?

Avio, provider of solid boosters for the Ariane family of launchers for nearly 30 years, has been cooperating with France's CNES space agency since 2010 under FLPP to develop the POD-X solid propulsion demonstrator. POD-X features a modular structure for hot-firing tests that can be adapted to simulate various motor configurations of propellant load (segmented or monolithic) as well as internal thermal protection, the nozzle or other subsystems.

What will be the resulting competitive edge?

This flexible test article could then be used to explore new configurations for Ariane and Vega solid motor upgrades as well as for the development of Next-Generation Launcher booster stages.

→ P80 NOZZLE

Herakles

Programme

vega

Other applications

ariane 5 ariane 6

What is it for?

As Vega's first stage, the P80 solid rocket motor has the same diameter as Ariane 5's solid booster stages (EAPs). Herakles has developed another evolution of its nozzle, adapted to Vega's requirements and introducing advanced low-cost technologies that could be reused for future evolutions of Ariane 5's boosters.

What is the technology challenge?

A European leader in thermostructural composite materials since the 1970s, Herakles (formerly Snecma Propulsion Solide) has been producing nozzles for Ariane 5's EAPs since the programme's inception and has since been upgrading its design towards fewer elements in order to reduce production costs.

What is European industry's expertise?

Ground qualified in 2008 and flight-proven through the Vega maiden flight in 2012, the P80 nozzle features a high-performance, simplified nozzle architecture using cost-effective and lighter carbon phenolic material, with a monolithic throat and an innovative flex-seal bearing design that incorporates new materials for reduced torque moment and enhanced thermal protection.

What will be the resulting competitive edge?

This new nozzle architecture both simplifies the assembly – thus reducing production costs – and improves the performances in terms of mass, thrust vector control and robustness.

→ ZEFIRO SOLID ROCKET MOTORS

Avio

Programme vega

Other applications vega

What is it for?
To achieve the performance requirements for the Vega launch system in terms of payload lift capacity and recurring production costs, two new solid-propellant motors have been introduced.

What is the technology challenge?
Avio, provider of solid rocket boosters for the Ariane family of launchers for nearly 30 years, has developed a family of solid-propellant motors derived from its earlier Zefiro Z16 ground-fired demonstrator, but featuring a new lightweight filament-wound composite casing.

What is European industry's expertise?
The Z23 is loaded with 23.9 tonnes of propellant and delivers 1196 kN of thrust at sea level with a burn duration of 86.5 seconds. The smaller Z9A features the highest mass fraction for solid motors in its category: its 10.1 tonne propellant load delivers 313 kN of thrust in vacuum for 128.6 seconds. Both are loaded with HTPB 1912 propellant and use a 1.9 m-diameter carbon epoxy casing low-density EPDM (ethylene propylene diene monomer) insulation as well as a flexible joint nozzle with electromechanical actuators for thrust vector control. The Z23 was ground-qualified on 27 March 2008 and the Z9A on 28 April 2009. Both were successful on the Vega maiden flight in 2012.

What will be the resulting competitive edge?
The two motors are key in keeping the cost down for the Vega launch system and ensuring its competitiveness on the export market.

> **The success of Vega's maiden launch is the result of eight years of hard work towards the development of a new launch system, the first ever to be made completely out of carbon fibre. The successful mission not only opens a new door to future space technology, it also gives us even more impetus to continue our R&D activities and push the boundaries of access to space.**
>
> Pier Giuliano Lasagni
> *Head of Avio Space Division*
>
> Avio press release
> February 2012

→ STRUCTURES AND MECHANICAL ENGINEERING

ESA–S. Corvaja

→ LIGHT, STIFF AND CAPABLE

Any gain in the dry mass of a launch system translates into a higher payload capacity, more so if the gains are made in the upper parts of the launcher. This means an increase in competitiveness, either by launching more payload mass with a given design, or by enabling the launch of heavier payloads on a smaller vehicle. Europe's expertise in advanced manufacturing processes for metallic parts and composite structural elements has already been recognised and exported widely, while its competence in thermal protection systems and sound mechanical designs has led to many technology firsts. These are tremendous assets from which the design of future generation of launch and space vehicles will have to benefit in order to get the best performance return from propulsion systems while being able to adapt to all kind of new mission requirements.

→ ELECTROMECHANICAL THRUST-VECTORING SYSTEM

SABCA

■ Programme

vega

■ Other applications

vega

ariane 6

ixv

pride

■ What is it for?

Traditionally, large rocket stages rely on hydraulic actuation systems for thrust vector control (TVC). For instance, solid rockets execute the motor's nozzle-steering commands issued by the launcher's onboard computer software to reach the desired trajectory. Hydraulic TVC requires a large tank of hydraulic fluid.

■ What is the technology challenge?

Replacing the hydraulic TVC with electromechanical TVC allows a major reduction in the mass and complexity of stages, and thus an improvement in performance, cost reduction and competitiveness. The use of electromechanical TVC on Vega's P80 motor is a first for a solid motor of that size and opens up new possibilities for future developments.

■ What is European industry's expertise?

SABCA, provider of actuation systems of Ariane 5's EAP booster stages as well as for the Vulcain 2 engine, has developed electromechanical TVC systems for all of the Vega stages. Each system is composed of two electromechanical actuators (EMAs), a battery, an interconnection harness and a power-control electronics box, which embeds a computer-based control system to achieve high-precision and high-speed nozzle motion. SABCA has qualified the four elements as well as designed and manufactured all the components inhouse with the exception of the batteries (from Saft, France) and the AVUM upper stage's EMAs (from Moog, US).

■ What will be the resulting competitive edge?

SABCA's lightweight EMA technology inherited from Vega is also being used for controlling the aerodynamic surfaces on IXV, with the addition of a brake mechanism to keep the flaps locked when required.

→ FRICTION STIR WELDING FOR WELD SEAMS

MT Aerospace

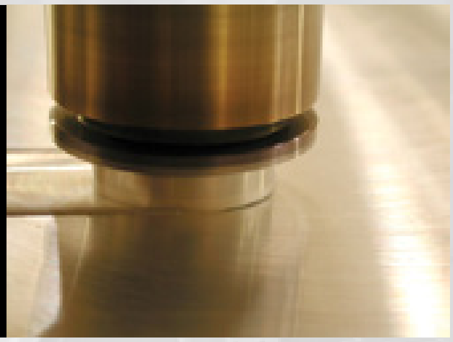
■ Programme

ariane 5

■ Other applications

ariane 6

future launchers



■ **What is it for?**
The development of a new cryogenic upper stage to increase the performance of Ariane 5, at a similar cost as the current upper stage, as well as for Ariane 6, implies a major effort in the reduction of structural mass and recurring costs while meeting complex mechanical and thermal requirements to support more complex deployment missions. MT Aerospace is thus implementing a step-by-step technology roadmap to introduce and qualify new technologies to manufacture lightweight tanks.

■ **What is the technology challenge?**
Friction stir welding, a solid-state joining process, was invented by The Welding Institute (TWI), a British independent research and technology centre. It uses a non-consumable rotating tool that passes along the abutting edges of two rigidly clamped metallic parts. The tool intermixes the two parts, transforming them into a softened state that allows the metal to be fused using mechanical pressure.

■ **What is European industry's expertise?**
MT Aerospace has been designing and manufacturing tanks and structural parts since the very early days of Ariane.

■ **What will be the resulting competitive edge?**
This technique provides major advantages such as high robustness of the process, little alteration of the material properties and higher structural mass efficiency than traditional welding. It also allows a reduction of recurring costs. MT Aerospace will apply this technology to two of the 5.4 m-diameter circumferential welds on the liquid hydrogen tank.

> **"In addition to the launcher's skirt, on Vega we also provided the actuators for the motor, like on Ariane. These actuators are no longer hydraulic but electro-mechanical, and we also developed the command box as well as the software, which processes the commands sent to the actuators by the onboard computer."**
>
> Daniel Blondeel
> *CEO of SABCA*
>
> *La Libre Belgique*

→ SPIN FORMING FOR THE TANK DOME

MT Aerospace

Programme

ariane 5

Other applications

ariane 6

future launchers

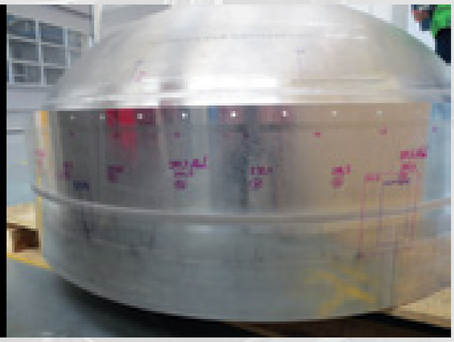
What is it for?
To ensure the lowest possible structural mass with optimised cost, MT Aerospace will apply spin-forming to produce the lower dome on Adapted Ariane 5 ME upper stage's liquid oxygen tank.
MT Aerospace is also carrying out studies on the spin-forming of cryotank domes for the future European launch system.

What is the technology challenge?
This process drastically simplifies the manufacturing of large tank domes by eliminating complex steps such as machining and welding required by traditional assembly of gore panels.

What is European industry's expertise?
MT Aerospace has already introduced spin-forming in the series production of propellant tanks for the Ariane 5 ES upper stage and the Automated Transfer Vehicle propulsion module.

What will be the resulting competitive edge?
MT Aerospace's patented spin-forming technology has already been recognised by international partners and constitutes a strong competitive edge for European space industry.

→ ALUMINIUM–LITHIUM ALLOY CRYOGENIC TANK



Thales Alenia Space

Programme

flpp

Other applications

future launchers

What is it for?
The use of high-energy cryogenic propellant is key to achieve high-lift performance for a launch system. However, the low specific mass of liquid hydrogen requires large tanks that have to contain the pressurised cryogen, be insulated, carry the loads and absorb the aerothermodynamic pressures and resultant thermal stresses. Significant mass and cost reductions can be achieved through the replacement of conventional aluminium alloys by lightweight and high-stiffness Al–Li alloy.

What is the technology challenge?
Thales Alenia Space Italy, which has been producing propellant tanks for US Delta vehicles for more than a decade and is a world-leader in space-qualified pressure vessels for human spaceflight, has teamed with MT Aerospace of Germany – provider of Ariane and Automated Transfer Vehicle tanks – to develop a subscale Al–Li demonstrator tank using innovative processing and manufacturing techniques.

What is European industry's expertise?
While MT Aerospace is investigating the Al–Li spin-forming of the domes, Thales Alenia Space is studying the structure milling for the reinforcement of the tank barrel panels. Friction stir welding will be used for the assembly of the various elements. The tank designed for leak-before-burst will undergo non-destructive examination. The demonstrator tank will then be submitted to cryogenic filling and draining before going for a proof test up to the limit loads and eventually up to burst.

What will be the resulting competitive edge?
The use of advanced materials and manufacturing technologies, as well as the cooperation between two industrial leaders in the domain of space-qualified tanks, including joint material procurement and technical standardisation, will be key to maintaining European industry's competitive edge in the space transportation business, both for launch systems development and the export of subsystems.

→ NANOPOLYMER LINER FOR COMPOSITE CRYOGENIC TANK

Synpo

Programme

flpp

Other applications

future launchers

What is it for?
The use of lightweight composite material to replace metallic parts in structural elements of launchers is a good way to improve the performance of a launch system.

What is the technology challenge?
New problems arise with composite cryogenic tanks, such as material compatibility with liquid oxygen and liquid hydrogen, as well as microcracking caused by very low temperatures and leading to leakage or even structural damage. The risk of leaks is more likely because of the very small size of hydrogen molecules. In the past, this has been a showstopper for various advanced projects.

What is European industry's expertise?
A former national chemical research institute with more than 60 years of expertise in polymers, Synpo is working as a subcontractor to EADS-CASA – a leader in composite materials – in advanced carbon fibre reinforced polymer (CFRP) structures for cryogenic applications. Microcracking is caused by the brittleness of the epoxy resins and the differences in the thermal expansion coefficients between the epoxy matrix and carbon fibre filler under cryogenic conditions. To address this, Synpo is developing special polymeric liners for the inner wall of composite tanks and investigating the addition of nanoparticles to the binder in order to achieve very low permeability to cryogenic propellant.

What will be the resulting competitive edge?
Once achieved, the proper maturity of this unique technology will allow the combination of CFRP cryogenic tanks with more conventional non-cryogenic structures for designing highly integrated lightweight structures for future launchers.

→ ADVANCED TECHNOLOGIES FOR COMMON BULKHEAD INSULATION

Air Liquide

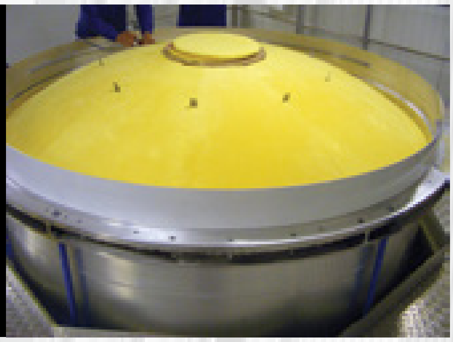
Programme

ariane 5

Other applications

ariane 6

future launchers



What is it for?
The Adapted Ariane 5 ME upper stage has a common bulkhead between the liquid hydrogen and liquid oxygen tank. Since liquid oxygen is stored at 90K and liquid hydrogen is at 20K, the temperature gradient between the two tanks might cause excessive hydrogen evaporation, especially during the long coasting phases as well liquid oxygen subcooling.

What is the technology challenge?
The bulkhead has to be covered with an effective but lightweight thermal insulation that can be glued onto the orthogrid metallic surface and keep its characteristics while wetted by liquid hydrogen.

What is European industry's expertise?
Air Liquide, a world leader in cryogenics for more than a century and a provider of cryogenic tanks and insulation for Ariane since the programme's inception, has developed advanced thermal insulation materials that reduce heat losses by a factor of three compared to their predecessors. This technology has been tested and validated on subscale demonstrators through all the main phases of a standard mission: tank chilldown, propellant filling, pressurisation to 3 bar and draining. It is now adapted to the specific requirements of Adapted Ariane 5 ME: compatibility with specific stiffeners and X-ring area without performance degradation, environment-friendly production and other industrial aspects, as well as behaviour in microgravity conditions, which favours capillary effects in the material.

What will be the resulting competitive edge?
This technology and the common bulkhead design will reduce the structural mass of the Adapted Ariane 5 ME upper stage and thus increase its payload capacity to orbit.

→ MEMBRANE-BASED CRYOGENIC PROPELLANT MANAGEMENT

Air Liquide

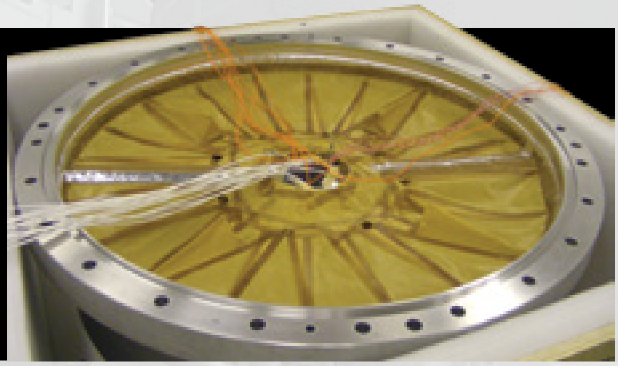
■ Programme

flpp

■ Other applications

ariane 5

ariane 6



■ What is it for?

Future launch systems must be capable of complex deployment missions through multiple engine restarts and long coasting phases. Achieving them with a manoeuvrable cryogenic upper stage requires the development of efficient and reliable cryogenic propellant management technologies.

■ What is the technology challenge?

Under the FLPP Cryogenic Upper Stage Technologies project, Air Liquide, a world leader in cryogenic fluids management for more than a century, has developed, building on its past experience, a concept based on continuous settlement of the propellant during the coast phase.

■ What is European industry's expertise?

Cryogenic membranes inside the tanks prevent the liquid from spilling and wetting the upper side of the tank, and reduce the settlement time of the propellant on the lower side while preserving a temperature gradient inside the tanks to reduce the heat flux into the liquid hydrogen.

■ What will be the resulting competitive edge?

This new technology would improve the use of propellant while reducing the overall stage mass by making ullage thrusters unnecessary, thus improving the payload lift capacity. It is also proposed for Adapted Ariane 5 ME's upper stage.

> **We have to think in the long term. A launch system doesn't come out of the blue all of a sudden. It is made of competences that have to be acquired and mastered over ten, twenty or even forty years. And that means that all along the way, we need to rely on people who firmly believe in them.**
>
> Benoît Potier
> *Chairman & CEO of Air Liquide*
>
> Roundtable, 50th anniversary of Air Liquide's Sassenage site, 29 October 2012

→ GAS SEPARATOR FOR CRYOGENIC PROPELLANT MANAGEMENT

Airbus Defence & Space

■ Programme

flpp

■ Other applications

ariane 6

■ **What is it for?**
Under the FLPP Cryogenic Upper Stage Technologies project, Airbus, prime contractor of Ariane 5's upper stages, is studying alternative solutions for cryogenic propellant management during the lengthy coast phases that are often necessary between engine ignitions for complex deployments.

■ **What is the technology challenge?**
Once the engine is restarted, its thrust is sufficient to settle the fluids, so the only need is to deliver enough propellant to ensure proper ignition and early powering-up. Airbus's propellant management system consists of a passive device mounted at both tank outlets using capillary forces to guarantee a certain amount of bubble-free liquid propellant to feed the turbopumps without risk of cavitation under all engine restart and operating conditions.

■ **What is European industry's expertise?**
Airbus has been prime contractor for all of Ariane's upper stages and cryogenic stages, as well as for the propulsion module on the highly manoeuvrable Automated Transfer Vehicle. As part of the technology maturation experiments to demonstrate the liquid hydrogen and liquid oxygen gas separator, concepts were developed and flown on the Texus-48 sounding rocket in November 2011. The six minutes of microgravity provided the environment to simulate the different phases of flight. The complex phenomena that appear during microgravity were continuously monitored from the ground and recorded onboard in high definition. The results are supporting the validation of models for both technical concepts. This first flight was performed with liquid nitrogen to ease cost, safety and thermal constraints. Investigations are under way for further sounding rocket experiment flights with the actual cryogenic fluids.

■ **What will be the resulting competitive edge?**
This low-cost and lightweight solution would ensure high manoeuvrability through multiple restart while preserving the payload performance of a future cryogenic supper stage.

→ JETTISONABLE VERSATILE THERMAL INSULATION

Thales Alenia Space

■ Programme

flpp

■ Other applications

ariane 6

future launchers

■ **What is it for?**
Despite the requirement for high manoeuvrability, with multiple engine restarts and long coast phases to ensure the capability for complex deployments, a large part of the launch market is likely to remain in the traditional geostationary transfer orbit (GTO) segment.

■ **What is the technology challenge?**
The additional equipment required for complex manoeuvres and integrated into the upper stage will be unnecessary for such missions and, as extra dead weight, will affect the payload performance.

■ **What is European industry's expertise?**
Under the FLPP Cryogenic Upper Stage Technologies project, Thales Alenia Space, a specialist in lightweight structures, is investigating jettisonable versatile thermal insulation (VTI): panels attached to the stage to protect the tanks' basic insulation during atmospheric ascent.

■ **What will be the resulting competitive edge?**
This VTI could either provide efficient thermal management of the propellant on missions requiring long coasting phases or simply be dumped once the atmosphere is cleared on GTO missions to increase the payload mass performance and the vehicle's competitiveness

→ DEPLOYABLE VERSATILE THERMAL INSULATION

RUAG Space

■ Programme

flpp

■ Other applications

ariane 6

future launchers

■ What is it for?

Thermal protection requirements for cryogenic upper stages during complex deployment missions with multiple engine ignitions and coasting phases should not significantly increase the stage's dry mass or reduce the overall performance, all the more so if the stage is also designed to serve classical missions to geostationary transfer orbits, with less demanding thermal control requirements.

■ What is the technology challenge?

Design of a lightweight and flexible thermal insulation system that could be adapted to specific mission requirements.

■ What is European industry's expertise?

Building on its large experience in space mechanisms as well as in thermal systems for all kinds of spacecraft, mostly based on multilayer insulation, Ruag Space is developing a concept of additional thermal protection through a lightweight deployable shield that would be stored during ascent and deployed in orbit along the stage to cover the cryogenic propellant tanks and reduce heat transfers.

■ What will be the resulting competitive edge?

This low-cost and lightweight solution would ensure effective thermal control of a future manoeuvrable cryogenic supper stage while preserving its payload performance.

→ LIGHTWEIGHT THRUST FRAME

Dutch Space

■ Programme

flpp

■ Other applications

ariane 6

future launchers

■ What is it for?

Designed to transfer heavy loads from the propulsion system to the vehicle's structure while withstanding harsh thermal conditions from the proximity of engines and strap-on booster plumes, thrust frames tend to be heavy structures, usually relying on quite conventional axisymetric configurations to ease load constraints. Moreover, aerodynamic requirements, in particular to limit buffeting, and their role as an interface to many vehicle subsystems and to the launch pad turn them into very complex and heavyweight components.

■ What is the technology challenge?

Dutch Space, which provides thrust frames for Ariane 5's Vulcain and HM-7B engines, is studying new thrust frame concepts based on innovative materials and structural configurations.

■ What is European industry's expertise?

The proposed designs would feature lightweight structures either made of composite material or of a combination of composite and metallic parts. They will have to withstand the large thermomechanical loads caused by the proximity to cryogenic propellant tanks, as well as high levels of internal loads within the composite material itself. Different resins and fibre systems compatible with the thermal requirements as well as various manufacturing processes have been evaluated. Representative thermoset and thermoplastic panels for the conical part are being manufactured and tested.

■ What will be the resulting competitive edge?

Significant reductions in the vehicle's dry mass will translate directly into an increase of payload performance.

→ COMPOSITE Y-RING

Sonaca

Programme

flpp

Other applications

future launchers

What is it for?
The architecture of expendable launch vehicles is based on a succession of cylindrical tanks with spherical ends connected together by cylindrical or conical skirts. Sometimes, these cylindrical structures are connected to conical frames, either to support propulsion systems or payload adaptors. Connections between these various shapes introduce discontinuities, which create mechanical stresses.

What is the technology challenge?
The interfaces between cylindrical and conical or spherical shapes involve Y-rings, which have to withstand complex mechanical constraints, either by transmitting thrust from propulsion systems or by supporting loads from upper parts. In current launch vehicles, these Y-rings are made of metallic materials, produced through traditional forging processes. In order to reduce mass, in particular for the upper parts of launchers, future Y-rings could be made of lightweight carbon fibre reinforced polymers (CFRPs).

What is European industry's expertise?
Sonaca, an aerospace company with a long expertise in composite material structures for both aeronautical and space applications, has been investigating their use for the design of a segmented Y-ring based on Airbus specifications.

What will be the resulting competitive edge?
Manufacturing a Y-ring through processes like Resin Transfer Moulding could significantly reduce both the mass of large-diameter structures and their production cost, in particular if small segments, produced with smaller tooling and autoclaves, are selected. This technology is likely to improve the competitiveness of European launch systems and space composite industry.

“Space is by definition an international affair. In the past we had national projects, but the time for national ambitions is gone. We are now mainly building parts – crucial ones – for major European projects, led by the European Space Agency or other partners. The Dutch space industry has become an export market. There are few companies, which focus only in the space market. Developments are complex, multidisciplinary and technically challenging. The role of government is far from finished, although private funding is also plying an increasing role in space infrastructures.”

Bart Reijnen
CEO of Dutch Space

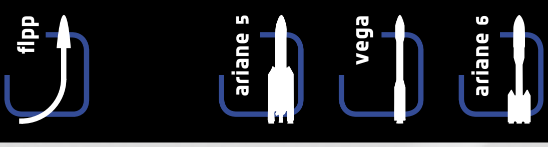
Bit&Chips
2 December 2011

> Our company has been a major industrial partner in European space programs from the outset, i.e. for more than 40 years. Europe is our home market. We lay the foundations here for our market success further afield. Above all, it is ESA programs that enable Ruag Space to acquire the technologies and the know-how to go on to enjoy success on the commercial market.
>
> Peter Guggenbach
> *CEO of Ruag Space*
>
> *SatMagazine*
> September 2012

→ COMPOSITE INTERSTAGE STRUCTURES AND PAYLOAD ADAPTORS

EADS-CASA

Programme **Other applications**



What is it for?
In order to achieve important mass and cost reduction objectives, EADS-CASA is investigating the use of lightweight and high-stiffness carbon fibre reinforced polymers in the design of structural elements such as payload adaptors, interstage skirts or cryogenic tanks, using either monolithic, stiffened skin or sandwich technologies, in order to define optimised solutions for various applications.

What is the technology challenge?
EADS-CASA is a leader in composite structures for space applications, already providing structural elements for Ariane 5 and Vega.

What is European industry's expertise?
The objective is to achieve both cost and mass reductions as compared with similar structures currently in production, by the use of less expensive materials and simpler structural concepts that could be manufactured through more automated processes. Solutions under evaluation include the elimination of aluminium rings and rivets and the use of monolithic elements reinforced with stringers and frames. Technical feasibility will be demonstrated through the design, manufacture and test of representative demonstrators such as a subscale Ariane 5 and a full-scale Vega interstage structures or a full-scale payload adaptor.

What will be the resulting competitive edge?
Mass savings in these upper structures of the vehicles translate directly into payload capacity increase, which in turn will improve the vehicles' competitiveness. This field of European expertise has already led to international export. This aspect of European industry's competitiveness would also benefit from major advances in technology.

→ PAYLOAD FAIRING

Ruag Space

Programme

vega

Other applications

ariane 5 vega ariane 6

What is it for?
Fairings encapsulate payloads in a controlled environment, protecting them from high temperatures, solar radiation, dust, moisture and rain before launch as well as extreme acoustic conditions, aerothermal flux and mechanical loads during ascent.

What is the technology challenge?
Since they have to withstand the high dynamic pressure conditions while passing through the dense layers of the atmosphere before being jettisoned at high altitude, they need to be both extremely stiff and lightweight in order not to degrade the vehicle's payload capacity.

What is European industry's expertise?
Designer and provider of Ariane payload fairings since the beginning of the programme more than 30 years ago, Ruag Space has flown over 220 units on Europe's Ariane and US Atlas launchers. Vega's fairing is based on the same sandwich technology as the Ariane and Atlas fairings. It consists of two shell sections made of an aluminium honeycomb core covered with layers of carbon fibre reinforced polymer. Its outer surface is covered with cork insulating tiles to protect it from the heat generated by the fast-moving launch vehicle. Nearly 8 m long and 2.6 m in diameter, the fully outfitted composite fairing has a mass of only 530 kg thanks to its innovative design.

What will be the resulting competitive edge?
Vega's fairing development is the latest in a series that have positioned Ruag Space as a world leader in this market and contributes to the competitiveness of the European launcher industry.

→ PLASMA WIND TUNNEL TEST TECHNOLOGY

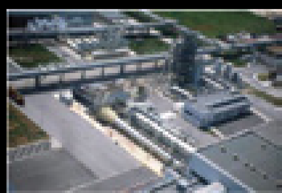
CIRA

Programme

ixv

Other applications

pride



What is it for?
When returning from orbit, a vehicle has to dissipate all of the kinetic energy it acquired at launch. This dissipation usually materialises in the form of very high aerothermal loads when reentering the dense layers of the atmosphere.

What is the technology challenge?
To simulate the extreme conditions experienced by reentering vehicles, Italy's CIRA aerospace research centre has developed the Scirocco plasma wind tunnel facility, which is considered to be the most advanced in the world, along with a centre of excellence in aerothermodynamic research and simulation.

What is European industry's expertise?
This facility will be used to qualify the performance of IXV's thermal protection system under flight-representative aerothermal conditions, at temperatures of up to 2000°C and fluxes of up to 800 kW/sq m. The test campaign will assess the performance of critical elements, verify model assumptions and check design margins that will define the vehicle's flight domain. The tests will be run on the thermal protection and the hot structure developed to hold it as well as on the design of the interfaces – the seals and insulation layers between the different subassemblies.

What will be the resulting competitive edge?
CIRA's Scirocco is a strong asset for future European or international developments of future vehicles designed for Earth or planetary atmosphere reentry.

→ CERAMIC THERMAL PROTECTION

Herakles

■ **Programme** ixv

■ **Other applications** pride

■ **What is it for?**
Ceramic composite materials are promising for thermal protection systems for vehicles designed to perform atmospheric reentry, on Earth or on another planet. Much lighter and more resistant to higher temperature environments than metallic systems, they are particularly suitable for thermal protection over the areas of a vehicle that will have to endure the highest fluxes. Moreover, unlike ablative thermal protection systems, they are reusable.

■ **What is the technology challenge?**
Thanks to its involvement in various national defence programmes and in the development of nozzles for European and international launch vehicles, Herakles (formerly Snecma Propulsion Solide) has become a leading provider in thermostructural materials and is now one of the few companies in the world with the technical knowhow and the industrial facilities to produce ceramic composite materials for space applications in such large dimensions.

■ **What is European industry's expertise?**
On IXV, the company developed and manufactured a large part of the ceramic thermal protection system such as the single-piece ceramic nose and the windward assemblies, which consists of 30 ceramic tiles. It also provides insulation layers and stand-offs. With IXV, Herakles has the possibility of flight-qualifying a full-ceramic composite thermal protection system solutions for a reentry vehicle.

■ **What will be the resulting competitive edge?**
This technology will be key for future developments in reentry systems, either manned or unmanned, in Europe or at international level, opening new domains of cooperation for European industry.

→ ABLATIVE THERMAL PROTECTION SYSTEM

Avio

■ **Programme** ixv

■ **Other applications** pride

■ **What is it for?**
Ablative thermal protection is an efficient way to dissipate heavy heat fluxes at reentry, with most of the energy being dispersed with the removed material. Moreover, it has the tremendous advantage of being relatively inexpensive compared to other thermal protection materials such as ceramic composites, as well as being easy to install.

■ **What is the technology challenge?**
With Ariane and Vega, Avio has acquired a very strong expertise in the production and use of the class of materials and related technologies.

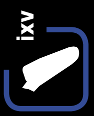
■ **What is European industry's expertise?**
On IXV, Avio manufactured the Ablative Thermal Protection System Assemblies for the lateral, the leeward and the base sides of the vehicle using efficient and lightweight materials, based on flight-proven ablative thermal protection technologies inherited from Vega.

■ **What will be the resulting competitive edge?**
This technology of simple and low-cost ablative thermal protection materials is an asset for the development of future simple and low-cost reentry systems, as well as for reducing the cost of more ambitious vehicles as complex as IXV.

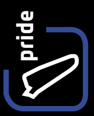
→ BODY FLAP TECHNOLOGY

MT Aerospace

■ Programme



■ Other applications



■ What is it for?
The capability to perform controlled manoeuvres at hypersonic speeds while reentering the atmosphere is of paramount importance for future high-precision return systems. It would also limit the dynamic constraints on their payload or crew.

■ What is the technology challenge?
IXV will demonstrate such a capability with a pair of moveable, load-bearing, stiff and heat-resistant control surfaces. This pair of body flaps will be exposed to very high thermal fluxes and temperatures.

■ What is European industry's expertise?
MT Aerospace, which designed, manufactured and qualified the body flap assembly for the NASA/ESA X-38 reentry vehicle, is in charge of the development, manufacture and qualification of IXV's Body Flap Assemblies based on ceramic composite materials. Each consists of a body flap, hinged thermal protection with dynamic seals, flap supports and bearings, thermal protection for the electromechanical actuator, a rod with high-temperature bearings and a flexible high-temperature resistant bellow, all of which will be exposed to extreme aerothermomechanical conditions and which represent a major technology challenge.

■ What will be the resulting competitive edge?
Flight demonstration and qualification of moveable control surfaces based on such ceramic composite high-temperature material will open up new possibilities for future developments in reentry systems, in particular for future manned or unmanned space exploration applications. Integrating international industrial teams in these domains will give European industry a competitive edge.

> **"The development period for new launchers averages about 10 years. The challenge for us is to develop our products gradually, to simplify complex issues at the same time, to minimize costs as well as to develop solid technologies and also light materials that can withstand enormous loads."**
>
> Hans J. Steininger
> *CEO of MT Aerospace*
>
> *Tefen Tribune*
> Winter 2009

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